Systems Energy Analysis for California

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The Issue

As required by Assembly Bill 1007, the California Energy Commission is preparing a plan to increase the use of alternative fuels in California. The plan will identify strategies to reduce emissions of greenhouse gases and other pollutants, to increase fuel diversity and reduce vulnerability to external events, and ultimately to slow down or reverse the rate of environmental degradation associated with economic and demographic growth. Normally, the planning process focuses on economic resource allocation, that is to say, on analyzing the economic costs of policy choices, implicitly assuming that if enough funds are made available, any option is feasible. This is reasonable when relatively small, incremental changes are being considered—for example, an increase in vehicle fuel efficiency standards. However, in analyzing potential large-scale, long-term changes to patterns of energy production and consumption, it is crucial to consider not only the economic costs, but also the physical and ecological viability of different options.

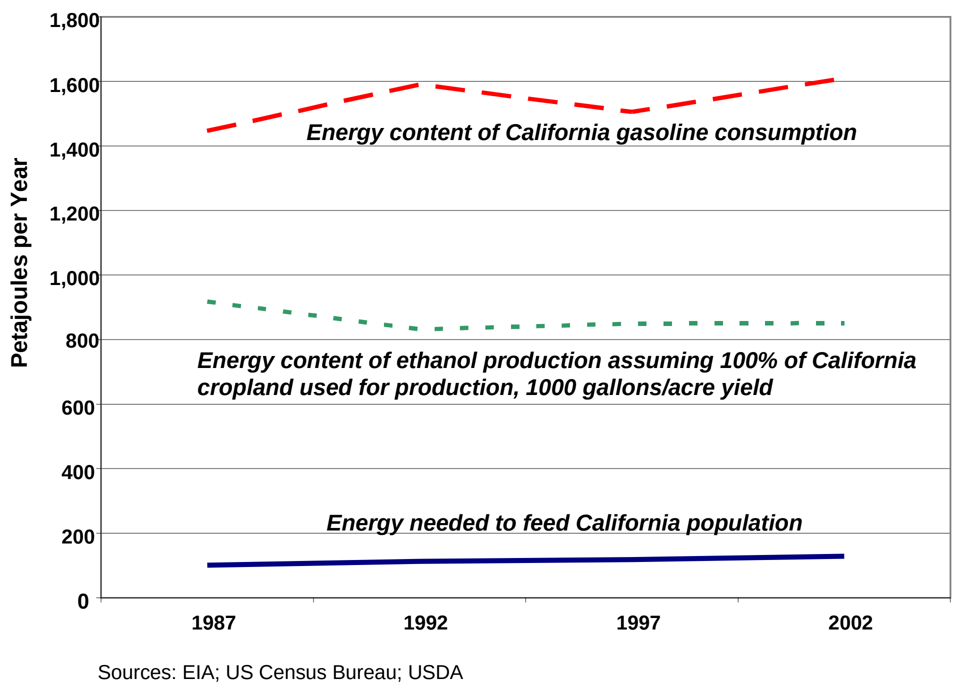

Figure 1: Gasoline, ethanol, and food energy policy must account for complex trade-offs among resource availability, economics, environmental effects, etc. For example, using more biomass for fuel could limit biomass availability for food. This project applies concepts from ecological foodweb analysis to develop a physically based method of accounting for energy production and consumption.

Conceptual problems arise, for example, around the issue of large-scale replacement of fossil fuels by biofuels. The most basic physical question is whether, under currently credible conditions, the amount of energy contained in a gallon of biofuel is greater than the energy required to produce it. Similarly, while it seems intuitively obvious that the widespread use of agricultural products for fuel could severely impact food production, the actual impacts have not been adequately described (Figure 1).

Controversy arises in part because standard economic methods incorrectly equate the availability of money to pay for a resource with availability of the resource itself. This makes it very difficult to incorporate real physical constraints into the analysis. What is needed is an alternative methodology that accounts for all the relevant inputs and outputs in physical rather than economic terms. As the world heads into a future where physical constraints will be more significant than economic constraints in determining viability, this approach will improve our ability to define and implement different energy paths.

Project Description

This project—funded by PIER's Environmental Exploratory Grants Program—will develop a mathematically consistent, physically based accounting of energy consumption and production within the California economy, inspired by concepts developed in ecological analysis of food webs (food networks) for describing complex, evolving systems of interdependent agents. Food web analysis characterizes species in terms of their role in production and consumption processes, and categorizes them into *trophic* levels.[1,2,3] The trophic level represents the number of necessary processing steps between primary production and an appropriate food source for the organism. Patterns of energy transmission between different levels, and the evolution of the size and species composition of the food web, are the primary physical processes represented in the model.

Because the economy is, in a sense, the ecosystem created by human society,[4] trophic concepts from ecology extend in a fairly straightforward way to the description of energy use in modern economic systems. This methodological approach also provides a clear and logically consistent framework for describing the interaction of the human economy with the larger environment. The proposed accounting methodology differs from existing analyses of energy balances in four fundamental ways:

1. The systems of inputs and outputs is measured in units of mass, not units of energy.
2. Boundaries are clearly defined by trophic (production) level.

1. Drossel, B., and A. J. McKane. 2003. Modelling Food Webs. In *Handbook of Graphs and Networks: From the Genome to the Internet,* S. Bornholdt and H.G. Schuster (eds.). Wiley-VCH, Berlin.

2. Holt, Robert D., John H. Lawton, Gary A. Polis, and Neo D. Martinez. 1997. Trophic rank and the species-area relationship. *Ecology* 80:1495–1504.

3. Post, D. M. 2002. The long and short of food-chain length. *Trends in Ecology and Evolution* 17:269-277.

4. Odum, Howard T. *Environment, Power and Society: The Hierarchy of Energy.* New York: Columbia University Press, rev. ed. 2007 (orig. pub. 1971), esp. Chapter 6.

3. Food production processes are included in the accounting system.
4. The accounting system addresses time explicitly.

As a specific application of the model, this project will evaluate the physical viability of large-scale substitution of biofuels for fossil fuels. The methodology will be used to define the range of what is physically possible and to identify the trade-offs that may be required by constraints on land, water, and so forth. The economic or social desirability of different scenarios will not be examined in this preliminary project.

PIER Program Objectives and Anticipated Benefits for California

This project offers numerous benefits and meets the following PIER program objectives:

- **Develop cost-effective approaches to evaluating and resolving environmental effects of energy production.** Climate change from fossil fuel production has been identified as a major threat to the natural systems on which the state depends. This study proposes a methodology for explicit evaluation of the physical constraints associated with alternative energy development paths.
- **Providing environmentally sound, safe energy.** Biofuels may be a key solution to providing a renewable, potentially carbon-neutral fuel for power production and transportation. However, before widespread biofuel production can commence, it is imperative that its physical limits, resource use trade-offs, and environmental impacts are examined at a system level. This project will explicitly analyze these physical constraints, assessing the trade-offs among water, land, nutrients, and other key ecological elements in diverting biomass to human use.

Final Report

PIER-EA staff intend to post the final report on the Energy Commission website in fall 2008 and will list the website link here.

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